A RAND NOTE

The Air Force's Munitions Requirements Process (The Nonnuclear Consumables Annual Analysis)

Gordon B. Crawford

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PREFACE

The four services have elaborate, but very different, procedures for estimating their wartime nonnuclear munitions requirement. These procedures provide inputs to their budgets and Program Objective Memoranda (POM) and are subject to review and comparisons by the Office of the Secretary of Defense. Each procedure has been studied and is being described, with suggested improvements, in a research report. [1,2]

This Note evaluates the Air Force methodology for calculating its nonnuclear War Readiness Material (WRM) munitions requirements (commonly known as the Nonnuclear Consumables Annual Analysis or NCAA). Suggestions for potential improvements are included.

These reports are part of ongoing research in the study entitled "Review and Improvement of Munitions Acquisition Processes" under the Acquisition and Support Policy program. The study was sponsored by the Office of the Assistant Secretary of Defense for Production and Logistics under the auspices of RAND's National Defense Research Institute, the OSD-sponsored Federally Funded Research and Development Center at RAND.

SUMMARY

The Air Force's Nonnuclear Consumables Annual Analysis (NCAA) details the annual computation of the WRM munitions requirements. This Note examines the process and its outputs and inputs. The potential for bias in some inputs, which may bias the mix of weapons computed by the requirements computation, is investigated. Several suggestions for potential improvements are included.

Some of the improvements pertain to the treatment of uncertainty about the number of targets that can be killed with a given number of weapons. The most important potential improvement deals with the consideration of the efficiency of a weapon—the ability (or lack of it) to kill a target in a minimum number of sorties.

The early days of a war are generally acknowledged to be target rich and sortie limited. One way to kill additional targets in the early days of the war is to buy and maintain additional aircraft and trained flight crews and base them in theater, or keep them ready to deploy quickly. Another way is to use more efficient munitions. The suggested improvement to the NCAA is intended to achieve more effective sorties early in the war by bringing more balance to these two methods.

ACKNOWLEDGMENTS

This research incorporates the thoughts and suggestions of many others. Among them Lieutenant General Glenn Kent (ret.) was successful in making the importance of the efficiency of munitions clear. Robert Hume, then Chf. AF/AD/ENYS, took the time to explain the elaborate and complex models used to compute aircraft attrition rates. Major Dennis Coulter, AF/XOXFC, has patiently answered innumerable questions about the NCAA process. Sal Culosi of Systems Research and Applications Corporation drew on his substantial experience with the process and provided many important suggestions.

This Note has benefitted from suggestions and data from RAND colleagues David Kassing, Matthew Goldberg, and Gary Mills.

CONTENTS

TABLES

I. INTRODUCTION

This Note evaluates and suggests potential improvements to the Air Force methodology for calculating its nonnuclear weapons requirement. More specifically, the models discussed here are used for the War Readiness Material (WRM) requirement and do not calculate the peacetime training requirement. The Munitions Planning Division (AF/XOXFC), Deputy Director for Force Development, Directorate of Plans, HQ USAF, has responsibility for the WRM weapons requirement, and the methodology for generating that requirement.[1]

XOXFC publishes the Nonnuclear Consumables Annual Analysis[3] (NCAA) in the fall of each year. In preparation of the NCAA the air-to-air requirement is calculated for the current year, the last year, and the intervening years. The air-to-surface requirement is calculated for the first and last year only. Each year's NCAA gives the number of weapons required, by type, for the five years of the Program Objective Memorandum (POM) years plus, for comparison, the number required in the year preceding the first year of the computation. The NCAA also briefly describes the computation methodology and gives most of the input data used.

There are basically three different requirements computations reported in the NCAA. Additive requirements are typically a straightforward computation of the needs for special weapons or other expendable items such as Tanks, Racks, Adaptors and Pylons (TRAP). Threat Oriented (TO) calculations are performed for weapons designed to counter a given threat, such as runway interdiction weapons. The TO calculation starts with the number of the target to be destroyed and then calculates the number of the weapon required. The Level Of Effort (LOE) calculation, dealing with air-to-surface munitions, is more complex. The LOE calculation recognizes that many weapons may be suitable for each of a wide variety of targets. It attempts to calculate the weapons (and aircraft) mix that will maximize the target value killed using "least cost to kill" weapons.

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[1] AF/XOOT has the responsibility for the peacetime training requirement. The peacetime missile requirement is broken out in the Theater Air Missile Program. Other training needs are covered in different appropriations. At a little over $200 million the peacetime requirement is a small part of the total munitions requirement. The Air Force air-to-air training requirement is primarily one of training up to the point of release of the weapons. The weapons released, if any, are apt to be inexpensive compared with those that would be released in combat.

In the most recent NCAA the air-to-surface LOE weapons, which account for almost all munitions in terms of numbers and bulk, resulted in approximately 68 percent of the dollar requirement, the Air-Air missiles were 15 percent of the dollar requirement, and the Air-Surface TO weapons accounted for 18 percent of the requirement.

The following section provides background and discusses some of the inputs to the NCAA process. Section III is devoted to the straightforward computation of the additive requirement and the TO requirement. Section IV contains a detailed discussion of the models involved in the LOE calculation. The different weapons that may be used with a given aircraft type against a given target type may have substantial variation in the efficiency of a weapon as measured by the expected number of sorties required to kill the target. The Air Force LOE criterion for selecting the "best" weapon to kill a target is based on the "least cost to kill" and gives little consideration to efficiency. A method for including efficiency in the LOE calculation is described in Sec. V. The inclusion of this criterion could have a substantial effect on requirements in many cases.

The results of the current LOE calculation are, in large part, driven by the input attrition rates. The procedures for estimating these rates are discussed in Sec. VI. Section VII addresses the disconnect between the models used to calculate the weapons requirement and the weapons procurement process. Section VIII provides a brief summary.

II. GUIDANCE AND UNCERTAINTY IN THE NCAA

THE DEFENSE GUIDANCE

Official guidance comes from several sources. The Defense Guidance (DG) [4] specifies the sustainability objectives [3, p. 2-1] and directs the Air Force to procure certain weapons in quantities adequate to achieve specified objectives. [3, p. 1-1] These objectives are followed carefully in the NCAA.

The DG specifies that consideration be given to land and sea attrition. The attrition factors used by the Air Force are taken from earlier RAND work.[5]

The DG is specific [4, p. 52] about the importance of the early days of the war: "As munitions requirements evolve with the introduction of new items, the Services will compute a mix of current and new munitions, within the available production constraints and resources that will *maximize early combat power and sustain combat objectives*." (Emphasis added.) The NCAA does not give adequate attention to the early days of the war. Section V suggests a means of modifying the LOE computation in the NCAA that would meet this criterion and would provide balance between the costs of achieving more wartime sorties by purchasing more aircraft and achieving more wartime sorties by purchasing more efficient munitions.

The DG [4, p. 52 (S)] states goals in terms of a least cost criterion. The suggested modification to the NCAA is consistent with this criterion.

The DG mentions [4, p. 53] the use of pipeline assets. To the best of my knowledge the NCAA does not consider the effect of these assets, which are probably insignificant.

OTHER GUIDANCE

The number of aircraft sorties used in the calculation of weapon requirements are drawn from the War Mobilization Plan (WMP-5).

XOXFC computes "Standard loads" for each aircraft and munition. A standard load is the average load a given aircraft will be expected to fly in combat, taking into consideration the mix of munitions and fuel tanks that will be required in view of the intended basing and the locations of the likely targets. It will vary from theater to theater and may vary from base to base. The requirements computations are checked to insure

that the weapons requirements do not exceed the upper bounds of sorties available as established by the WMP-5.

Nowhere is it asserted that maldistribution of weapons must be considered, and nowhere in the calculations is it given explicit consideration. Some TO weapons are probably stored at air bases, but air bases may be overrun. In Europe LOE weapons are, in large part, stored in depots because of the lack of storage facilities at air bases, creating an acknowledged transportation problem at the onset of war. The munitions are expected to be delivered by truck. Aside from the question of available truck capacity, there is a lot of uncertainty about the condition of the highways, not only the degree of disruption the enemy will cause but also the extent to which civilians attempting to evacuate will clog them.

As an example of the size of the problem, if a wing of F-16s devoted to air-surface was carrying Mk 82s and flying a 3.0 sortie rate, it could deliver approximately 1300 Mk 82s in a day, well over 300 tons of munitions. Carrying bombs on rails, a truck with a 40' bed will accommodate 42 Mk 82s. With the bombs palletized the number doubles, but adhering to U.S. load limits reduces the load to about 75–80 Mk 82s, equating to about 17 truck loads of bombs per day.

The maldistribution problem is severe, but in Europe at least, it is primarily a storage and transportation problem. Buying more efficient munitions would ease the problem. The munitions requirements models do not explicitly consider any aspect of the maldistribution problems.

HANDLING UNCERTAINTY IN THE NCAA

The task of calculating the Air Force's future wartime munitions requirements faces enormous uncertainties. In addition to the problems of maldistribution, the list would include:

1. The time of the war—how far into the future?
2. The opponent(s) and the theater(s).
3. The length of the war.
4. The amount of money that should be spent on munitions.
5. The importance of each of the target types.

6. The size of the important target set destroyed by the other services and the allies.
7. For those targets to be destroyed by the AF, the effectiveness of the available munitions.
8. Aircraft attrition and the number of sorties available for the targets and munitions, by time period.
9. The ground and sea attrition of munitions.
10. The rate at which the enemy will repair and regenerate targets.

Many of these questions are properly outside the arena of munitions requirements modeling and are dealt with, if at all, in other studies. These other studies and considerations provide inputs to the NCAA process.

In the NCAA the Air Force, like the other services, deals with the time of the next war by planning for a given level of readiness for each of the POM years. The plan invariably provides for much greater readiness in the out years than in the immediate future.

The theater, the opponent, and the length of the war are spelled out in the DG. These data, while imperfectly known, are set by the guidance and the associated uncertainty are not further considered in the NCAA.

The amount of money available for munitions is not treated explicitly. Section VII considers the disconnect between munitions requirements and munitions acquisition.

The value of killing a given target in a future war is very uncertain indeed. Such uncertainties are ignored in the NCAA process. Although "target values" are assigned for use in the HEAVY ATTACK model, these values are sometimes considered a knob to be used to insure that the outputs of HEAVY ATTACK are reasonable and in agreement with earlier years' runs.

The size of the target set to be destroyed by the other services and the allies and the size of the resultant target set to be killed by the Air Force are taken from the Air Force Planning Guide (AFPG)[6]. Past determinations of this target set by XOXFC have utilized inputs from the other services and then set the size and shape of the Air Force's slice of the pie. It is freely admitted that this slice is probably larger than the other services would concede. Although ad hoc, this overestimation of the size of the target set to be killed is one way of treating uncertainty about the size of the target set that the Air

Force must destroy. In the future the Joint Chiefs of Staff (JCS) will allocate the threat (beginning with the air threat) to the services.

The effectiveness of munitions is the responsibility of the Air to Surface Weapons Effects Division (AD/ENYW) of AF/AD. Exercises, especially the Weapon System Evaluation Program (WESEP) at Eglin AFB, contribute to the data used. The kill probabilities (Pks) provided to XOXFC are often estimated under favorable conditions and are degraded (by XOXFC, with concurrence from the Munitions Working Group) for the pressures of war before being used in the NCAA. Despite the attention to this parameter, the effectiveness of weapons in a future war is speculative.

In most instances the number of a target that will be killed with a given number of a specified weapon is the sum of the number killed in essentially independent trials, and as such can be assumed to be approximately normally distributed. Estimates of the mean and variance may be made with the Pks produced by the weapons effectiveness studies. Thus this particular type of statistical uncertainty is amenable to modeling in the NCAA process.

Estimates of aircraft attrition are the subject of Sec. VI. Estimates for the first day/first wave attacks are modified for use in the NCAA so that the resultant attrition will be consistent with the rates published in the WMP. The uncertainty about actual attrition rates to be experienced in a future war is not given further attention. In part this is explained by the need of planners throughout the Air Force for one set of numbers representing the sorties expected to be flown in the first time periods of the war.

The likelihood of ground and sea attrition of munitions is considered in that estimates are taken from earlier RAND research. [5]

Throughout the remainder of this Note the notion of modeling uncertainty is used in a very limited sense—it addresses the statistical uncertainty in the numbers of targets that will be killed with a given number of weapons, or the associated problem of the statistical variation in the numbers of weapons required to kill a given number of targets, or, where explicitly addressed, the uncertainty surrounding the numbers of munitions lost to ground and sea attrition. The other forms of uncertainty mentioned are not considered below. They are probably best considered outside the NCAA process.

KILLING A TARGET

In the language of the NCAA a target is assumed killed when "on the average, [the weapon/munition] will cause at least, the specified damage to particular target elements." Although this is less than perfectly clear, it appears that a target is assumed to be killed at least 50 percent of the time if a munition hits within a specified (munition dependent) area around the target. The Pks used are the probabilities that the given munition will hit within this critical area.

III. THE THREAT-ORIENTED AND ADDITIVE CALCULATIONS

ADDITIVE CALCULATIONS

The NCAA deals with more than weapons. Additives, referred to in the NCAA as "Offline Calculations," are calculated for many expendable requirements and for special missions such as Search and Rescue.

The additive requirement is calculated by using an expected Expenditure Per Sortie Factor (EPSF) and number of applicable sorties. In addition to munitions, EPSFs are calculated in the NCAA for:

a. Gun Ammunition
b. Target Illumination/Photoflash Cartridges
c. Target Markers
d. Chaff
e. Mines
f. Defense Suppression (Anti-radiation munitions)
g. Fuel tanks

The additive calculation is illustrated by the following example (taken from [3, p. 2-18]).

EXAMPLE: Assume 91 percent of the F-4D sorties are assigned to the air-to-surface role. Also, assume 70 percent of those sorties are loaded with two 370-gallon fuel tanks. Finally, when these tanks are carried in an air-to-surface sortie assume they will be jettisoned about 18 percent of the time. Then the following EPSF can be calculated:

$$\text{EPSF} = .2293 = .91 \times .70 \times 2 \times .18$$

With this EPSF, if 2000 F-4D sorties are planned, the requirement is $.2293 \times 2000 = 459$ tanks.

Comments on the Additive Calculation

Although tanks are not properly munitions, several important aspects of this example deserve attention, and the following comments are generally applicable to similar calculations.

First, some of the numbers are fairly "hard," in that right or wrong they come from other guidance. Examples are the sorties planned for the F-4D and the proportion assigned to the air-to-surface role.

That 70 percent of those sorties will carry two 370-gallon tanks can, perhaps, be reasonably estimated in view of the intended basing of the F-4Ds and the probable locations of the targets they will be attacking. Beyond that, the estimation that 18 percent of the time the tank will be jettisoned is pretty soft.[1]

The F-4 is, in a clean configuration, a Mach 2 fighter. If attacked or jeopardized the pilot is likely to drop whatever air-to-surface munitions and auxiliary tanks he has and defend himself or make a prompt exit. Any estimate of the probability of this occurring in a specific future environment is highly conjectural. It happens that the United States fought a limited number of air-to-air engagements with the F-4 in Southeast Asia, but that was against a very different enemy in a very different setting. For the bulk of the fighters in our current and future inventory the United States has never entered a serious engagement in anger. For these fighters the data are even softer.

This calculation is clearly an expected value calculation and appears to ignore statistical uncertainty about the number of tanks that will be jettisoned. This uncertainty could be explicitly considered in the following way: Assuming that different sorties are independent, and each sortie has a probability P, $P < 1$, of expending the given item, then the number of sorties that will be accommodated by one of the item is a geometric random variable with mean $1/P$ and variance $(1 - P)/P^2$. Hence the number of sorties that can be accommodated with n of these items is approximately normally distributed with a mean and variance that are n times the mean and variance of the number that can be accommodated with one of the item. If it is desired to accommodate a number N of sorties with confidence "a," then the number n of the item that are required can be

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[1]Throughout this Note the suggestion that certain data may be "soft" is not a criticism of the model or the modelers. The performance of weapons and weapon systems in a future war is necessarily speculative. To the credit of XOXFC, the parameters used in these calculations are generated by the Commands and have been approved at various levels within the Air Force.

determined from these means and variances and the suitable value from a table of the cumulative normal distribution.

The outcome of this computation would be a new EPSF (which contains a cushion for statistical variation in the number of sorties obtainable with a given number of tanks) that would be an input to the HEAVY GOAL model. A disadvantage of handling uncertainty this way is that the new EPSF depends on N, the final number of sorties allocated to the aircraft and mission; the use of the EPSF—rather than computing a fixed additive—is dictated by the uncertainty regarding N at this stage of the NCAA. Fortunately, the numerical dependence on N of the EPSF that has a statistical cushion is small (assuming that N is known to within a reasonable approximation).

As the calculation is now used, a cushion for statistical variation may be included if the opinion consulted for some of the softer data has erred on the side of procuring an excess of tanks, or if tanks exist in excess anyway, or if many of the missions could, in a pinch, be flown with feasible alternative configurations. Attempting to handle the uncertainties with precise but extremely soft (both the mean and the variance mentioned above depend on soft estimates of P) distributional assumptions may not improve the estimation of requirements. An explication of how the experts have accounted for uncertainty could add information that is currently missing. However, the realities of providing a credible publication that justifies part of the Air Force's budget may make that an unlikely addition to the NCAA.

In practice, it is the EPSF factor that is input to the HEAVY GOAL model, the last model in the LOE calculation. Sea and land attrition is also added in that model, which is described below.

THE THREAT-ORIENTED (TO) CALCULATION

The requirement for the TO weapons is computed by theater. TO weapons are designed for specialized targets and, to an increasing degree, expensive. The TO calculation includes all the air-to-air missiles: the radar missiles, AIM-7E, AIM-7F/M, and AIM-120 or AMRAAM, and the IR missiles, the AIM-9P/L and AIM-9M. The air-to-surface munitions treated in [7] by the TO calculation are DURANDAL and

DAACM, anti-runway munitions, and TACIT RAINBOW and HARM, which are anti-SAM munitions.[2]

Formerly SAC's nonnuclear weapons requirements received special priority and were calculated by SAC. They are currently calculated by XOXFC. The method of calculation involves looking at the output of the HEAVY ATTACK model (described below) and isolating the targets that XOXFC judges were killed in insufficient numbers. These targets are then "assigned to SAC" and the munitions requirements are calculated with an additive or a TO calculation.

The TO calculations begin with the USAF "share of the threat" as published in the AFPG. In theory this share results from inputs from other services regarding the portion of the threat they expect to kill, but there is currently no interservice agreement on the share of the targets each is expected to kill. As mentioned, the JCS will assume responsibility for allocating target shares to the services.

Next in importance is the Pk and the firing doctrine (shoot-look-shoot, or shoot-shoot-look). Dual-shot Pks are derived from the single-shot Pks by assuming that the probability of kill for each of the two shots is independent. The single-shot Pks are derived from combat exercises, principally the Weapon System Evaluation Program (WESEP) at Eglin AFB, and are degraded by XOXFC as deemed necessary to account for the pressures of combat.

The assumption of independence in calculating the dual-shot Pks induces an error, although it is probably small compared with the accuracy of the data: If the aircraft is not in firing position, or if the on-board systems are not working properly for the first shot, the second shot is likely to be made in similar circumstances. For these reasons the dual-shot Pks calculated with an assumption of independence overstate dual-shot relative to single-shot effectiveness.

The DG now asserts that TO weapons should be procured in sufficient numbers to insure that a certain percent of the threat is destroyed with a certain level of confidence. To this end it is assumed that the number of a given target type killed with n weapons is a normal random variable with mean np and variance np(1 - p), where p is the combat

[2]In addition to the TO calculation, there is an additive calculation to determine the number of missiles required for a "basic load," which is a one time requirement that equips each aircraft with the defensive missiles it will need. Among other things, the basic load covers the missiles that are lost as aircraft are attrited. The missiles needed for strategic defense are also an additive to the TO calculation.

degraded Pk that is effective for the firing doctrine. With this assumption the number of missiles required to kill a certain portion of the threat with a given level of confidence (as mandated by the DG) can be derived from a table of the cumulative normal distribution. After the TO calculation XOXFC checks to insure that there are enough sorties available to deliver the munitions. If not, the requirement is lowered.

Land and sea attrition of missiles is calculated using estimates derived from earlier RAND research. [5] Air attrition is generously treated with an additive, referred to as the "basic load," thus providing an additional cushion against under resourcing as a result of uncertainty. [3, p. 3–53].

Comments on the TO Calculation

In the TO calculation the Air Force's approach to the calculation and the recognition of the random number of the threat killed with a given number of missiles seems sound. The accuracy of the computation depends primarily on the accuracy of the estimate of Pk and the size of the threat.

Here, as elsewhere, there should be concern about the validity of the inputs. The Pk for missiles that have never been used in combat, and whose total annual consumption is small, is a pretty soft number. The extent of the "combat degradation" that is applied to the WESEP data is not documented in the NCAA, but that is also, of necessity, a subjective call.

IV. THE LEVEL OF EFFORT CALCULATION

OVERVIEW

The LOE calculation uses a series of models that digest a large collection of data and serially reduce it to arrive at the munitions requirement. The first model in the series, called WEAPONEER in [3] and SABER in [7] and below, uses detailed data from the Joint Munitions Effectiveness Manual (JMEM) [8] as well as target data from the AFPG and aircraft data, including standard loads. This model gives the expected number of kills per pass for each aircraft/target/weather/munition combination.

These outputs are combined with attrition data and cost data in the SELECTOR model, whose output lists combinations of aircraft, target, weather, and munitions ranked by their expected cost to kill the target. These lists are inputs to the HEAVY ATTACK model.

HEAVY ATTACK allocates sorties to targets, using an "average" Pk (taken to be a reasonable value given the munitions that might be used on this aircraft against this target). Then the weather bands are considered and the munitions are allocated to sorties to maximize the total value of the threat that is killed. Among the outputs of HEAVY ATTACK are the Expenditure Per Sortie Factors (EPSFs) that allow the last model, HEAVY GOAL, to quickly recompute munitions requirements when some of the scenario dependent inputs are changed, as is common in the NCAA process.

Following the detailed discussions of the individual models are comments on the LOE computations.

SABER—THE JMEM MODEL

The inputs to SABER are:

1. Weapons Effectiveness. From the JMEM, specific measures of weapon effectiveness:

    Mean area of effectiveness
    Vulnerable area
    Effective miss distance
    Bridge effectiveness index

2. Target Descriptions. Mobile and fixed target descriptions originate with theater intelligence, are coordinated with AF intelligence, and are documented in the AFPG, Vol. III. These targets and the rate at which the enemy may regenerate them are reprinted in NCAA [3, Sec. 3].
3. Aircraft Delivery, Weather. Weather conditions in the target area that may effect accuracy and efficiency of munitions delivery are divided into several sets or bands. The probability of each of these bands occurring on a randomly selected day is also used. [3, p. 2–10]
4. Delivery accuracy data are provided by JMEM/AS Delivery Accuracy Working Group.
5. Intervalometer—unguided weapons. SABER assumes continuous intervalometer settings and delivers all unguided weapons on a single pass. Intervalometer setting is computed to maximize damage for the conditions under consideration.
6. Aircraft Payloads: A "standard aircraft load" is input. The method of calculation is explained in [9] and is based on target locations and basing. The payloads used are given in [3, Sec. 3].
7. SABER Output: Using the target descriptions and the munitions data SABER computes the expected kills per pass for each aircraft/munition/weather/target combination. These data are passed to SELECTOR.

SELECTOR—RANKING THE MUNITIONS BY THE EXPECTED COST TO KILL

SELECTOR ranks munitions for each aircraft/target/weather combination; it computes the cost to kill a target by combining the SABER output with the expected cost of aircraft attrition, aircraft O&M costs on a per sortie basis, and munitions cost. The program ranks the munitions from lowest to highest cost to kill. The inputs to SELECTOR are:

1. Effectiveness data from SABER.
2. Aircraft payloads—the standard loads mentioned above.

3. Aircraft costs, both flyaway costs (for attrition) and wartime O&M costs per sortie from AF/ACMC.
4. Weapon costs. Weapon costs are given in [3, p. 2–13]. At this point weapons are described by their full designation, which specifies the choices of fuses, tail fins, etc. that make up the weapon. Item cost and weapon data are given in [3], in the Item Cost and Weight Report, in sufficient detail to compute the cost of the specific configurations under consideration. The source of the data is not given, but the data are straightforward and in substantial detail.
5. Expected aircraft losses per sortie for each combination of aircraft, munition, weather, and target are supplied by AD/ENY at Eglin. These loss rates are modified by drawdown factors that model the expected changes in attrition rates throughout a war [3, table, p. 2-15]. This table is supplied by XOXFC. The modifications are an attempt to match the WMP attrition rates, draw down figures, as well as modify them when judgment dictates. Attrition rates are considered in detail in Sec. VI.

For each time period and each combination of aircraft, munition, weather, and target, SELECTOR computes a cost per sortie including weapons cost, attrition costs, and wartime operations and maintenance costs. For each of these combinations the expected number of sorties required to kill is taken as the inverse of expected kills per sortie. The product of expected cost/sortie and expected sorties to kill gives the expected cost to kill for each combination.

Thus the cost to kill is computed as a function of the expected attrition cost, the munition cost, the operational cost per sortie, and the expected number of sorties required to kill the target. The efficiency of a munition, and the value of the additional sorties that would be available if a more efficient munition was used, are ignored (except for the possible effect on expected attrition). Even this effect is minimized in the attrition calculation by using a replacement cost for aircraft and ignoring all other life cycle costs, including the cost of a trained air crew.

Actually, several lists of preferred weapons are passed to HEAVY ATTACK, one for each weather band and time period.

HEAVY ATTACK—THE OPTIMIZING MODEL

HEAVY ATTACK has been described as a model that minimizes the cost to kill. Strictly speaking that is not true. HEAVY ATTACK does use the preferred munitions from SELECTOR, which are the munitions yielding a minimum cost to kill for a given aircraft and target combination. Using these preferred munitions, which heavily influence the requirements, and the constrained number of air-to-surface (A-S) sorties available by aircraft type, HEAVY ATTACK actually maximizes the target value killed.

As mentioned above, SELECTOR passes to HEAVY ATTACK the preferred munition for each combination of aircraft, weather, and target. Before the optimizing routine, HEAVY ATTACK uses data on the likelihood of the different weather bands, and the expected numbers of sorties to be flown in each, and selects the weapon that is best in the sense of having the least cost to kill averaged over all weather bands. Lord [10] mentions that this averaging before the optimizing procedure can have unusual results. A munition that is particularly effective in certain weather, but because of its cost, say, is a poor choice in other weather conditions, may never be chosen by HEAVY ATTACK. Instead, a weapon that has the "least cost to kill" when averaged over weather is passed to the optimizing routine.[1]

It has been emphasized that target values may resemble, but are not the same as, military worth. I was told that in a sense "target values" are a knob that is used in the repeated runs to make the output of HEAVY ATTACK reasonable and in reasonable agreement with previous years' munitions requirements and intended theater specific sortie allocations.

After achieving a run with satisfactory outputs the target list and the targets killed are compared. Any target that is not killed in sufficient quantity is then "given to SAC" and the needed munitions are calculated with a TO methodology.

The inputs to HEAVY ATTACK are:

1. Length of each conflict period.
2. Number of air-to-surface sorties for each aircraft for each time period. The number used is the number in the WMP, minus the number dedicated to air-

[1]The current model could be used to check on the importance of these observations by partitioning targets and sorties to weather bands, running the model once for each weather band, and looking at the sum of the munitions requirements and the target values killed.

to-air, TO air-to-surface, and "other" efforts, and minus the number assumed to be ineffective for air abort, etc.

3. The percentage of sorties that are considered effective in the air-to-air and the air-to-surface role are given in [3, p. 2–23].
4. The preferred weapons generated by SELECTOR, corresponding to each of the time periods.
5. The target types and quantities from AFPG.
6. The target values.
7. Weather information, from USAFE Environmental Technical Application Center, 10/76, and supplements.

The HEAVY ATTACK Output: EPSFs—expenditure per sortie factors, the average number of each type of weapon used by each aircraft divided by the number of sorties for that aircraft. The reliance on EPSF seems redundant in view of the details that are available at this point in the calculation. The problem is that the final run of HEAVY ATTACK will be approved only after a lot of feedback involving repeated runs with various parameters subjectively adjusted. This is deemed necessary to insure that this "final" run seems reasonable to all concerned. However, at this point in the POM process not all of the inputs, particularly sorties by aircraft by theater, have been fixed. Rather than go through a tedious series of computations, and an iterated review of the results as the expected number of sorties gets revised, the EPSFs are calculated and used in HEAVY GOAL as surrogates for the HEAVY ATTACK output when perturbed by changes in parameters such as the number of sorties available by aircraft type.

HEAVY GOAL—THE FINAL COMPUTATION IN THE SERIES

The major inputs to HEAVY GOAL include:

1. EPSFs from HEAVY ATTACK.
2. WMP sorties by aircraft type by theater.
3. Projected sea lane and intratheater attrition.
4. Projected inventory for beginning of planning period.
5. Weapon cost and weight.

HEAVY GOAL is a computer program that summarizes the output of HEAVY ATTACK and adjusts it as necessary for changes in the numbers of sorties or other data that were not finalized at the time of the HEAVY ATTACK run.

HEAVY GOAL uses the EPSFs and the programmed number of sorties to compute the number of each type of weapon expected to be used. It then increases this number with a multiplier to account for sea and land attrition.

HEAVY GOAL outputs include quantity, cost, and weight required, for each munition and each time period, by each theater. Consumption is summed by theater, to give stockpile requirements by theater. Munitions are described by their complete designation, which identifies the fuses, nose cones, tail fins, and other pieces needed to make up the complete munition.

The total worldwide WRM requirement for each item, including quantity, cost, and total weight, and the cost of the total requirement summed over all theaters and all munitions is given.

COMMENTS ON THE NCAA PROCESS

The biggest concern is the lack of consideration of the efficiency of munitions, that is the ability or lack of it to kill targets quickly. This is addressed in detail in Sec. V. A discussion of other, perhaps less important, issues follows.

Handling Uncertainty

One way of treating uncertainty about the adequacy of the munition requirement is to plan on killing more of the target than the expected share, which is done. Another way is to use pessimistic Pks. (In the case of a new and expensive weapon that has been funded on the basis of its intended effectiveness, this has some drawbacks.)

Another way of implicitly treating uncertainty about the number of targets that can be killed is to do a requirements calculation that leaves some of the interchangeable LOE weapons as surplus. This is done in the existing calculations—not all the old dumb bombs turn out to be needed, thus providing a buffer for error. Mitigating the effect of this buffer is that these surplus bombs are stored in the United States, which, one hopes, is not where they will be needed.

The additive calculation does not explicitly treat statistical uncertainty about the adequacy of the requirement. A possible procedure to include uncertainty in the additive calculation has been mentioned above.

Fortunately, the TO calculation does explicitly consider statistical uncertainty. (The TO weapons are not only expensive, they are also not interchangeable in the sense that the LOE weapons are interchangeable.) Hence it is important to explicitly consider the random variation in the needed number of each TO weapon.

Statistical uncertainty is not treated in the LOE calculation. It is reflected, if treated at all, in the subjective estimation of soft parameters. In part, ignoring uncertainty is justified by the nature of the calculation. The LOE calculation is not intended to calculate the munitions required to perform any specific task. The intent is to calculate the munitions needed to cost effectively maximize the utility of the sorties remaining after sorties have been allocated to air-to-air and air-to-surface TO weapons.

The Cost Data

It is wrong to use aircraft replacement cost as the cost of an attrited aircraft in wartime. It is also inappropriate to simply use replacement cost for complex weapons that require periodic maintenance or expensive storage. The Air Force cannot simply buy additional aircraft and flight ready crews and warehouse them and roll them out in theater when needed.[2] When the decision is made to buy these aircraft it has been implicitly decided that the value of the aircraft's contribution to war fighting and deterrence, over the life cycle of the aircraft, is worth paying the entire life cycle cost of the aircraft, including crew training costs.

Underestimating the aircraft value in this calculation results in the Air Force's making the decision to procure aircraft and accordingly size the fleet with one "aircraft value" in mind; then, in the weapons requirements computation the aircraft (and the Air Force) get short changed when the aircraft are valued at a substantially lower replacement cost. This has the effect of trading the cost of aircraft attrition, at a decidedly sub-par value, against the cost of more expensive munitions that may contribute to fewer aircraft losses. The underestimation is exacerbated by ignoring the

[2]Aircraft can be, and sometimes are, "mothballed." However, bringing an aircraft from a mothballed to a flight ready state is expensive, laborious, and time consuming. Nor is "almost mothballed" an attractive option. There is some evidence, and wide agreement among maintenance personnel, that if the number of flying hours per unit of time are allowed to become very small, the maintenance cost per flight hour becomes exceedingly high.

value of the crew that is also apt to be lost, and by ignoring all battle damage repair costs.[3]

Although aircraft replacement may be the wrong cost to use when computing the expected cost of attrition, finding agreement on the "right" cost may be difficult. The value for old aircraft that are near the end of their intended life cycle should be less than that for newer aircraft of comparable replacement cost.

The implication of increasing aircraft attrition costs would be to buy more of the smarter munitions. With aircraft attrition costs higher, expensive standoff weapons (typically with lower attrition rates) will become more cost effective. This also has the effect of tilting the requirements toward more of the munitions that will kill targets in a minimum of sorties—will kill more targets early in the war. These expensive, efficient weapons also have the advantage of requiring less space for storage on a per kill basis.

There is the recurring question of the appropriate cost for munitions that are already in the inventory. A popular point of view is that these are sunk costs, and hence the appropriate costs for the HEAVY ATTACK model are zero. This is in close agreement with the policy in the NCAA, which gives a zero cost to munitions in the inventory that have gone out of production. The popular view regarding sunk costs suggests that in addition to out of production munitions, a cost of zero should be given to, say, Mavericks procured last month, while Mavericks to be procured next month or next year should be valued in the HEAVY ATTACK model at their (approximately $100,000) replacement price.

The HEAVY ATTACK model is not run to evaluate the effect of munitions procurement on the federal budget. It is run to compute a cost effective mix of weapons for a future war. In this context assigning a cost of zero to the existing inventory of munitions is, by extension, equivalent to assigning a cost of zero to the existing inventory

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[3]The ratio of battle damaged to killed aircraft has historically been estimated at about 3:1. Current estimates of this ratio in a NATO war may be different. The only recent war fighting experience with modern aircraft has been in Israel's wars. Israel's experience is that most battle damage can be repaired quickly in wartime. Some residual amount will not be repaired at all, and an in-between number will keep an aircraft out of action long enough to effect a significant "cost." AFLC has responsibility for battle damage repair and can provide distributions for the amount of time to repair battle damage. These distributions should be converted to distributions of sorties lost and combined with the Opportunity Value of Lost Sorties (OVLS) described below. Aircrew attrition can also be estimated as a fraction of attrited aircraft and included in the attrition cost.

of aircraft. If aircraft have a cost of zero, why not compute a requirement for kamikaze attacks—flying the valueless aircraft into intended targets?

Old, out of production munitions have value. The price paid for them may be a reasonable surrogate for their value. This price, or a better surrogate if available, should be used instead of zero in the HEAVY ATTACK model.

Currently, most out of production munitions are fairly cheap. The inclusion of their price will have little or no effect on the computed mix of munitions. In the future, in view of the cost of munitions currently in procurement, the assigned cost of such munitions could make a difference; this question should be reviewed.

The current calculation ignores the storage and maintenance costs associated with weapons. Although for dumb bombs this may be unimportant, in the case of complex weapons with expensive maintenance costs, it should be considered. For these weapons, as with aircraft, using replacement cost undervalues the asset.

Technical Problems with the HEAVY ATTACK Optimizing Model

Successive years of requirements for each munition and the marginal buy requirement after existing inventory has been subtracted out, as calculated with an optimizing model, present a formidable mathematical optimization problem.

In a run of HEAVY ATTACK, the surface whose maximum is sought is the value of targets killed. The constraint is the number of sorties by aircraft type. The value of targets expected to be killed is expressed as a function of the aircraft/munitions combinations used to kill those targets. This defines the surface in n-dimensional space whose maximum is sought. The dimension of this problem is large, it is the sum of all the feasible aircraft/munition combinations that could be used to kill a given target, summed over all targets.

Suppose that the mix of munitions is sufficiently rich and diverse that there are very different mixes of munitions resulting in approximately the same kill for approximately the same cost. In particular, if this happens near the maximum of the function being maximized, then the computed dollar value required to kill the targets may be fairly robust with respect to the inputs and the numerical method used to find the maximum; however, the point (the mix of munitions required) that yields the maximum may be very sensitive to the inputs, and even sensitive to the mathematical technique used to determine the maxima.

In other words, if near the maximum the surface is fairly flat in one or more dimensions then there will be many points where the function is arbitrarily close to its

maximum, and some of these points may be well removed from the point that yields the precise maximum. There is evidence that this is the case with the HEAVY ATTACK model [10,11].

This is not a criticism of the modeling procedure, it is a statement about the complex mathematical nature of the optimization problem. A robustness of the dollar value of the requirement is the best that could be hoped for. The number of aircraft/munition/target combinations is too large to expect robustness of the point that yields the maximum.

Although an examination of the technical aspects of the optimization problem suggests that robustness of the net dollar requirement is all that can be expected, there are nonmathematical reasons to expect stability in all the outputs. As mentioned, as a result of the flatness of the surface near the maxima, varying the inputs slightly or even changing the numerical methods for finding the maximum may cause the location of the computed point that yields the maximum to change drastically. The coordinates of the point that gives the maximum yield the sortie allocation and munitions mix that result in the LOE requirement. If the point moves drastically as a result of small changes in the inputs, using such an optimizing model may cause the composition of the year-to-year requirement to vary wildly, and seemingly without any rational justification.

Publishing an NCAA that covers the POM years and shows the successive year's requirement for a given weapon jumping up and down wildly without clear supporting reasons would discredit the entire process. These reasons alone are sufficient to cause XOXFC to make adjustments to the input data and iterative runs of the HEAVY ATTACK model.

An important byproduct of the model is the allocation of sorties to targets that results in the stated requirement. The HEAVY ATTACK sortie allocations, which are largely driven by the input target values, may not be reasonable from a theater commander's point of view. Target values are an important but very imperfect measure of the military worth of a target. For instance, they ignore the dynamic aspects of war that cause the values of targets to change, both relatively and absolutely. They also ignore the geographical aspects of war that may cause a given target in one area to be much more important than that same target in another area.

For these reasons it is important that XOXFC compare the HEAVY ATTACK sortie allocation with the war plans of theater commanders. These comparisons can be

expected to require a change in the inputs and iterations with the model to achieve output that resembles the best opinions of how the war might be fought. Stabilizing the HEAVY ATTACK sortie allocation and pinning it to war plans that do not change drastically (without reason) from year to year also achieves a stable weapons requirement.

To a certain extent these iterations may seem to defeat the purpose of the complex model that sets out to achieve a mathematically optimum solution to the problem. The input data in this problem is, and will always be, soft. Insuring that the output agrees with the best thoughts on how the war will be fought may serve the dual purpose of achieving reasonable output and encouraging rational thought on the probable course of the war.

This fact has not been lost on XOXFC. The conjectured lack of robustness and the need for agreement with theater commanders' war plans may explain why there are many iterations with much discussion of the intermediate results and fine tuning of the inputs before agreement is reached on a HEAVY ATTACK run.

The Navy, in its LOE model, inputs sortie allocations against target types instead of computing them in an optimizing routine, as is done in HEAVY ATTACK. The iterative process with the HEAVY ATTACK model could be made simpler if the Air Force did the same.

V. CONSIDERING THE EFFICIENCY OF A MUNITION

Although HEAVY ATTACK is an optimizing model, it uses the preferred weapons for each aircraft/target/weather combination that are output from the SELECTOR model. This preferred weapon is chosen on the basis of a "least cost to kill" criterion, hence this criterion drives the weapons requirements. This cost is computed as a function of the expected attrition cost, the munition cost, the operational cost per sortie, and the expected number of sorties required to kill the target. The value of sorties missed because multiple sorties were used to kill targets with ineffective weapons is ignored.

In the early days of a NATO war there is general agreement that for the allied air forces the environment will be sortie limited and target rich. Moreover, killing targets during these early days is critical to the success of the allies. Unfortunately, the number of sorties required to kill a target is ignored in ascertaining the preferred weapon, except that it may affect the expected cost of attrition.

Currently even the attrition cost of requiring many sorties to kill is understated by using replacement (purchase) cost of the aircraft—as though aircraft can be purchased and stored until they are needed. The value of sorties missed as a result of using inefficient munitions in the early days of the war is totally overlooked.

In the philosophy of the HEAVY ATTACK model, it is acknowledged that the limiting constraint, especially in the early days of the war, is the number of sorties available. Throughout DoD planning there is general agreement that killing high value targets early in the war is extremely important. Hence a correct assessment of the cost of killing a given target with a given aircraft/munition combination must include a recognition of the value of the sorties required to make this kill using this combination. Consideration of this value is mandated by the potential shortfall of our sortie capability in the early days of the war, the richness of the target environment that could be attacked if more sorties were available, and the importance of killing these targets in the early days of the war.

The goal of using an OVLS is to attempt to achieve a balance between the cost of gaining additional sorties by buying aircraft and by buying more efficient weapons. The current practice of ignoring this imbalance and biasing the requirement toward cheap and inefficient weapons demonstrably degrades the value of the aircraft, hence the Air Force, in wartime.

THE OPPORTUNITY VALUE OF A LOST SORTIE

The decision to base aircraft in the theater and the cost of purchasing and basing them reflect implicit assumptions regarding the value of the sorties that could be made available during the first days of a war.[1] In setting the munitions requirement there is a need to consider the tradeoff between the munitions that are inexpensive to buy but may require many sorties to kill, and munitions that are expensive but efficient in the sense of requiring few sorties to kill.

Absent other explicit mitigating factors, if the added cost of making sorties available by killing targets with more efficient weapons is less than the added cost of gaining sorties by procuring more aircraft and trained flight crews, then the Air Force should purchase the efficient weapons. To do otherwise is to short change the Air Force and the taxpayer.

The choice of weapons in the Air Force LOE requirements methodology is largely driven by the choice of a "preferred weapon" for each aircraft/target/weather combination. In the SELECTOR model, this choice is made on the basis of the expected cost to kill the target, as expressed by the sum of cost of the munition, the product of the expected number of sorties required to kill and the (relatively small) operational cost of flying a sortie, and the (understated) expected attrition costs. None of these costs reflect the value of lost sorties—the value that could be achieved if more efficient munitions were used and the additional sorties were available for other purposes. In the early days of a NATO war the implicit value of a sortie, the OVLS, is apt to be very high. Ignoring this cost, or hoping that it is adequately captured in the expected attrition costs, will understate the need for efficient weapons, degrading sustainability with these weapons, or reducing the ability of the Air Force to kill targets quickly in the early days of the war, or both.

The existing series of munitions requirements models could easily incorporate estimates of the OVLS and use them in the munitions requirements process.[2] The

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[1]Throughout we make the assumption that the early days of the war are the most demanding (in the sense of the number of sorties and target kills required) for all types of aircraft. If this is not true, if there is an identifiable time frame that is more demanding for a given aircraft type, the following arguments can be modified in obvious ways.

[2]It would also be easy to modify SELECTOR to ascertain the preferred munition on the basis of the minimum expected sorties to kill. This ranking also has a disadvantage: If one munition is, say, three times as expensive as another but only 10 percent more efficient, the cheaper weapon would be ignored. Clearly both cost and efficiency are important. The OVLS is intended to bring balance to these costs.

SELECTOR model should be modified to add the product of the OVLS and the expected number of sorties to kill to the cost to kill as it is now computed.

This implicit value of sorties in a war, the OVLS, can be estimated by the cost (or savings) and the additional (or fewer) sorties that would be available if one more (or one less) aircraft were to be based in theater. With this framework a dollar value of additional sorties can be imputed. There may not be unanimous agreement on the method of computing this dollar value, but competing methods will at least provide a lower bound on the value of an added sortie in the early days of the war. In any event a well-reasoned attempt to estimate the OVLS would be preferable to ignoring it completely, as is done in the current method. One method of computing this value is suggested below.

ESTIMATING THE OVLS

A pragmatic and intellectually satisfying approach for estimating the OVLS is beyond the scope of this project. The following thoughts and numerical example are offered to better define what the OVLS means, and to enumerate some of the considerations that should be included.

The high value of kills early in the war may not be currently modeled in HEAVY ATTACK, but we have been told that target values can be made to depend on time in the model. Superficially, it seems that target values should be higher early on in keeping with the generally acknowledged importance of killing many targets in these time periods. It is a quirk of the optimization procedures used in the NCAA that increasing all target values in the early time periods without changing their relative values would have no effect on the munitions requirements and sortie allocations. The constraint is still the number of sorties available by time period, and the preferred munition would still be selected on the basis of cost to kill, not kills per time period.

The WMP, which uses decreasing sortie rates in the later time periods of a war, even for some aircraft for which there are attrition fillers, seems to implicitly expect a decreased need for sorties in the later time periods, suggesting that the value of sorties in these time frames has lessened. The WMP notwithstanding, some believe the expected decrease in the value of sorties is fictional. Other considerations, such as airbase attack, may result in a decrease in the number of available sorties without decreasing their value. The issue is clearly important but beyond the scope of this research.

If the planning went that far, we would expect the value of the remaining airframes to be about zero if the war was lost, but there would be some residual value attached to an airframe if the war was won, and there was a need to "enforce the peace."

ESTIMATING THE OVLS—AN EXAMPLE

To estimate the OVLS we begin by assuming the cost of aircraft based in theater represents an implicit assessment of the OVLS. Table 1 presents a Life Cycle Cost (LCC) analysis of the F-16 C/D, following AFR-173-13.[12] The LCC is then modified by assuming that the aircraft has a disposal value at the end of its life cycle and its value at the onset of a war depreciates linearly over its life cycle to the disposal value. It is further assumed that the war is won and the aircraft has a postwar residual value that is

Table 1

LIFE CYCLE COSTS, 24 PAA F-16C/D SQUADRON
COSTS, NO DISCOUNTING OF FUTURE COSTS
(Millions of 1988 $)

Aircraft procurement cost	13.5	x24	324.0
Support A/C increment	50%		162.0
Support and spares increment	33%	(of above total)	160.4
LANTIRN pods and munitions	0.0		
Total Procurement			646.4
Disposal value	20%	(of above total)	129.3
Disposal value per aircraft	1/24	times above	5.4
Initial acquisition and training	71.1		71.1
Total procurement and training			717.5
Shelter MILCON	48.0		
U.S. share of MILCON	100%		
Shelter construction			48.0
Capital costs			765.5
Annual operation and support	63.5		
Assuming 20 year	x20		
Life cycle O&S costs			1270.0
Total squadron LCC			2035.5
LCC per aircraft	x(1/24)		84.8

some fraction of its (depreciated) value at the onset of the war. The difference between the depreciated value at the onset of the war and the residual value after the war is called the Opportunity Value in Table 2. The Opportunity Value is prorated to sorties in Table 3. The resultant OVLS for the F-16C/D is given in Table 4 for each time period. The remainder of this section discusses the calculations in this table.

Although the following exercise uses fairly good estimates of procurement, support, and training costs from Air Force documents, these costs have been used with sortie rates and time periods that are hypothetical and do not reflect any war plan. This example is intended for illustrative purposes and to provide an idea of the order of magnitude of the OVLS.

The total procurement and training costs for 36 aircraft (a 24 PAA squadron plus a 12 aircraft increment) is 717.5 M$, or 29.9 M$ per aircraft. This is more than twice the replacement cost of 13.5 M$ that is used in the attrition calculation but still ignores the operating costs required to keep this aircraft available and its crew combat ready. The depreciated value of the F-16 C/D, including personnel costs, computed in Table 2 is between 85 M$ and 45 M$, depending on the year.

Air Force cost accounting typically ignores the disposal value of aircraft, yet many tactical aircraft continue to be used after the end of their supposed life cycle. To

Table 2

OPPORTUNITY VALUE TO BE PRORATED
TO EFFECTIVE WARTIME SORTIES
(Million $)

Year of War	Depreciated Value at Onset of War	Opportunity Value (Depreciated value less 30%)
1987	84.8	59.4
1988	80.8	56.6
1989	76.9	53.8
1990	72.9	51.0
1991	68.9	48.2
1992	65.0	45.5
1993	61.0	42.7
1993	57.0	39.9
1994	53.0	37.1
1995	49.1	34.4
1996	45.1	31.6

Table 3

PRORATING THE OPPORTUNITY VALUE OVER THE EXPECTED NUMBER OF EFFECTIVE SORTIES IN A WAR

Time period days	1–7	8–21	22–30	31–60	
Sortie rate	3.0	2.5	1.8	1.0	
Attrition rate	.03	.01	.005	.005	
Maximum number of sorties this time period	21.	35.	16.2	31.	
Expected number of sorties this time period[a]	15.75	29.66	15.67	27.92	
Expected number of effective sorties this time period[b]	14.49	27.29	14.42	25.69	
Relative weight of sorties this time period	4.5	3.0	2.0	1.0	
Total weight of effective sorties this time period[c]	65.20	81.87	28.84	25.69	
Total weight, all time periods					201.61
Proportion of Opportunity Value allocated to effective sorties in this time period[d]	.0223	.0149	.0099	.0050	

[a]Uses above formula for expected number of sorties per time period.
[b]Assumes 8% of sorties are ineffective for air aborts or other reasons.
[c]Product of expected number of sorties this time period and the relative weight per sortie.
[d]The quotient of the total sortie weight this time period divided by Total weight divided by expected number of effective sorties this time period.

Table 4

THE OPPORTUNITY VALUE OF A LOST SORTIE
BY TIME PERIOD
(Thousands of 1988 $)

Time period (days)	1–7	8–21	22–30	31–60
OVLS per sortie	1,137	760	505	255

minimize the overstatement of the OVLS a 20-year life cycle (instead of the more common 15 years) and a disposal value of 20 percent of the procurement cost have been assumed.

In keeping with the hypothesis that an aircraft is generally most useful and most valuable in its early years, and this value wanes linearly to its disposal value over its life cycle, the annual depreciation of an F-16 C/D is estimated to be its LCC less its disposal value divided by its hypothetical life cycle:

$$\text{Annual Depreciation} = (84.8 - 5.4)/20 = 3.97 \text{ M\$/year}$$

In addition to depreciation and disposal value, an aircraft also has a certain utility after the war—to "enforce the peace" if necessary or possibly to maintain a military presence or strength in other parts of the world. Although there is no reference to this in Air Force cost accounting that I know of, in the interest of not overstating the OVLS, I estimated the value of having the aircraft available after the war at 30 percent of the prewar depreciated value. Thus the opportunity value to be amortized over the war is 70 percent of the depreciated value. These values are given in Table 2.

If the length of the time period, the sortie rate, and the attrition rate are specified (and independence between sorties is assumed) the number of sorties until attrition, or the end of the time period, will have a truncated geometric distribution. (There is a question of whether to count the sortie suffering attrition—in the following it has been counted as a weapons delivering sortie.) If the per sortie probability of attrition is P and the maximum number of sorties in a time period is N, then the expected number of weapons delivering sorties can be shown to be equal to $(1/P)(1 - Q^N)$, where $Q = 1 - P$.

The following example (rather arbitrarily) gives weight 4.5 to sorties in the first time period, 3.0 to sorties in the second time period, 2.0 to sorties in the third time period, and 1.0 to sorties in the third time period. Sortie rates, attrition rates, and rates of

ineffective sorties due to ground aborts or other reasons are hypothetical rates and do not reflect actual WMP or NCAA rates.

Assuming a war in 1990, the F-16 C/D's opportunity value is estimated at 51 M$ in Table 2. Multiplying this by the factors developed in Table 3 gives the OVLS.

Thus, even with what may be generous assumptions regarding the disposal value of aircraft after their life cycle and the value of aircraft after a war these estimates of the OVLS are, in the first time periods, in excess of a million dollars and diminish to about a quarter of a million dollars in the last time period. These values are high compared with the other cost considerations used in computing the least cost to kill munitions in the SELECTOR model.

Including the product of these values and the expected number of sorties to kill a target (as a function of the chosen munition) would make efficient munitions preferred for most targets in the early time periods and, depending on the attrition rates, may make the efficient munitions preferred for all but the easy to kill targets in all time periods. Further escalating the weightings given to the early relative to the later time periods would increase the OVLS in the early time periods (probably with little effect on the munitions requirement, since the OVLS may dominate the calculation of cost to kill even at the above values) and make its inclusion less important in the later time periods. This may reduce the requirement for efficient munitions.

CONCLUSIONS REGARDING THE OVLS

Developing, using, and refining a satisfactory estimate of the OVLS are beyond the scope of this work. Indications are that these implicit costs should be considered and could have wide ranging importance in Air Force policy studies as well as weapons requirements computations. The idea also carries over directly to Naval aviation, and to varying degrees to many of the policy and requirements determinations in all the services.

Ignoring the OVLS in computing weapons requirements, especially with the Air Force methodology that is driven to select "minimum cost to kill munitions," is bound to result in buying fewer efficient munitions.[3]

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[3]After reviewing a draft of this Note, XOXFC staff mentioned that they may want to look at the OVLS in the future.

The importance of using a requirements methodology that places more importance on efficient weapons in the early days of the war could be quantified with the existing AF models, with only minor changes to the SELECTOR ranking procedure. In such a demonstration care should be taken to avoid being misled by the lack of robustness of HEAVY ATTACK mentioned above.

VI. ESTIMATING THE ATTRITION RATE

The LOE calculation generates the requirements for the bulk of the munitions and is responsible for approximately 68 percent of the dollar value of the munition requirement.

In the LOE calculation the choice of munition is driven by the preferred munitions list generated in the SELECTOR model. This list is ranked by the expected cost to kill a given target using a given aircraft/munition combination.

Given the aircraft, munition, and weather, the current method of calculating the expected cost to kill uses JMEM data from the SABER model to calculate the expected number of sorties required to kill the target. This number is multiplied by the expected cost per sortie using this munition/aircraft combination. The expected cost per sortie is the sum of the O&M costs per sortie, the munition cost, and the expected attrition cost. The expected attrition cost is product of the probability of attrition and the aircraft flyaway cost.

Thus, in the current LOE model, which ignores the OVLS, the driving factor is usually the probability of attrition or the attrition rate, because its multiplier—the aircraft flyaway cost—is far greater than the other factors. Moreover, estimating the attrition to be expected in a future war is clearly a difficult problem requiring many subjective judgments. Overestimating the attrition rate for inefficient dumb bombs relative to expensive munitions would drive the requirements models to overstate the requirement for the expensive munitions.

The attrition rate used in the NCAA models is a product of an expected attrition rate provided by AD/ENY for the first wave of attacks on the first day of the war and an attrition drawdown factor computed by AF/XOXFC. Attrition on the first day/first wave attacks are high: The attacks may be on targets on Pact soil and defenses are assumed to be intact. Hence the attrition drawdown factors are used to attenuate the first day/first wave attrition rates and keep attrition consistent with the WMP.

THE ATTRITION MULTIPLIER

The attrition multiplier is provided by AF/XOXFC. I was told that the goal in calculating the multipliers is to achieve an attenuated rate that would result in aircraft attrition comparable to the attrition rates published in the WMP.

The attrition multipliers are given in a matrix in the NCAA [3, p. 2–15]. Like the WMP attrition rates, they depend on the theater; but they also depend on the time period in the war—the later the time the softer the target defenses. (This assumption is also in line with the decreasing rates published in the WMP.)

The attrition multipliers do not depend on the munition. If the attrition rate used in the NCAA is biased low for expensive efficient munitions, that results from the bias in the estimates of the first day/first wave attrition rates, or the attrition rates will change differentially for different munitions as the war wears on. Estimating such differential rates is beyond the scope of current techniques; I have therefore concentrated on the likelihood of bias in the first day/first wave attrition rates.

THE FIRST DAY/FIRST WAVE ATTRITION RATES

The first day/first wave attrition rates are supplied by the Systems Survivability Division of the Air Force Armaments Division at Eglin AFB (AD/ENYS). The models used to calculate the estimates of these rates are complex, elaborate, and extremely detailed. They are explained in [13].

In view of the importance of the attrition rates, the models, philosophy, and process employed by AD/ENYS were examined in detail.

In general AD/ENYS is concerned with accurately estimating attrition rates as opposed to reconciling those rates with the WMP or with concern about the effect of those rates on the munitions buy requirement. Questions about subjective judgments and assumptions in the estimation process, and the influence of those judgments on the buy of expensive versus dumb munitions, brought out that Hume and his associates try not to consider this aspect of the downstream effect of their modeling assumptions. Influencing the mix resulting from the requirements computation does not appear to be a goal of their task.

The attrition data base is updated annually. In one recent year, as a result of a change in the modeling procedure, the attrition rates jumped up substantially. (They were then reduced for use in the NCAA process by using low attrition multipliers.) In the subsequent year, with additional knowledge and refined techniques, the rates were back in the ball park of the previous year's numbers. ENYS did not seem overly concerned with how their first day/first wave attrition rates compare with the WMP rates, or with anyone's predisposition about how the munitions requirement computation ought

to go. Their concern is with accurately estimating attrition in a way that is sensible, repeatable, and driven by as few soft assumptions as possible. (This is a tall task, hence the complexity and range of elaborate computer models used.)

In the past the Attrition Data Bank was summarized in an Attrition Data Handbook. As a result of inept use of these data, the Handbook is no longer published. Attrition data are released only by AD after AF/XOX approval. The AD/ENYS document [13] addresses only the philosophy, methodology, and approach used to generate attrition rates. In large part the report is motivated by a desire to seek constructive comments and suggestions on the methodology.

The philosophy in ENYS has been to divide a hypothetical attack into several different segments and model each segment as precisely as possible. For information on the likely tactics to be employed in attacking a target they rely primarily on expertise from the Tactical Fighter Weapons Center at Nellis AFB. For information on the effectiveness of weapons they rely on data generated by the Air to Surface Weapons Effects Division of AD at Eglin. The assumptions, the soft data, and the results of the attrition modeling are reviewed by a committee of the Munitions Working Group.

In keeping with the NCAA need, the attrition rates furnished by ENYS (the Attrition Data Bank) provide estimates of attrition for a given target, aircraft, munition, and weather band. The defenses that must be penetrated to reach the target are discussed below. The modeling considers two different aircraft types—a fast mover and a slow mover. These results are then scaled for other fast and slow aircraft by considering the ratios of vulnerable area and time within the range of the defenses (as affected by the ratio of the nominal speeds) of the specific and modeled aircraft. The actual weather modeled is the worst case within the weather band under consideration.

Within this framework several factors exert important influences on the attrition rates.

1. Weapon employment tactics drive the differences in attrition rates for different munitions.
2. The backbone of the attrition models is a many-on-many model that considers the important interactions in substantial detail. An encounter in this model between a particular aircraft and a specific defense is modeled using the output of one-on-one models that evaluate the potency of the defense.

3. Attrition can be heavily dependent on the placement and potency of the defenses. To model similar events that may occur in many places in a theater, ENYS uses representative areas and representative defenses. Estimates of the threat characteristics of Soviet defenses are provided by AF Intelligence. These characteristics are used to develop the one-on-one models whose output is used in modeling the air attacks.
4. The ENYS attrition models have no capability to model defense regeneration and repair. Moreover, it is assumed that the next wave of attacking aircraft is sufficiently far behind the first that no interaction occurs. The estimates are strictly for a first day first wave attack.

Basic Attack Concept

Although different in detail from case to case, attrition estimates for a given aircraft/munition/target/weather combination are modeled with repeated runs of a "single" attack. A raid of aircraft penetrate from the friendly side of the FEBA to the general area of weapons employment. As they penetrate, they use various techniques to evade, avoid, suppress and jam surface-to-air missiles, guns, and airborne interceptors in an effort to avoid attrition.

Near the weapon employment point they change to attack formation and begin maneuvering as needed to employ their weapons. The target may be defended by point defense missiles or guns. After employment the aircraft then turn away from the target and end their attack. The aircraft then return to enroute formation and egress back to the friendly side of the battle area. The attack is simulated in a Monte Carlo many-on-many model. Multiple replications of the attack yield an average attrition rate.

The attack model uses data from engagement (one-on-one) models for each individual threat/aircraft engagement. By using a number of runs, a variety of targets may be attacked with many different weapons and attrition statistics for all cases produced and stored. Later, as needed, these statistics are retrieved and presented in an easy to read format or stored on a digital data tape for further processing by subsequent weapon selection models.

The procedure uses the average attrition only. Other statistical information such as quartiles or the variance of the attrition experienced is calculated but not used in the NCAA.

If raids were accompanied by Wild Weasel anti-SAM flights, the effect of those previous flights is modeled in the potency of the defenses. With this exception the attrition rates do not consider the defense suppression that could occur as a result of sending aircraft in to soften defenses immediately before a raid.

The size of the raid may have a big influence—large raids tend to saturate the defenses and reduce overall attrition rates. This places increased importance on getting feedback from Air Force operations personnel to insure that raids and raid size are modeled in a realistic manner. Currently, within a theater and mission area, all raids are the same size, regardless of the munition.

The Structure of the Attack Profile

The attack is composed of three parts. The ingress portion is a series of straight lines from the friendly side of the FEBA to the attack start point. The weapons employment portion extends from the start point to a weapon employment point and then to an attack finish point. The egress portion is a series of straight lines from the finish point back to the friendly side of the FEBA. In the weapons employment portion the aircraft executes the maneuvers needed to properly employ the weapon.

These profiles are digitally represented as an 11 dimensional vector that depends on time. Time is recorded and advanced in increments of one second. The 11 dimensions are the displacements in the X, Y, and Z (altitude above ground level) dimensions, the velocity component in each of these dimensions, the air speed in knots, the heading, dive, and roll angle in degrees, and the number of Gs being pulled.

The attack profile is designed to reflect a realistic planned flight profile against the target in question, using a particular munition, with varying degrees of knowledge of fixed defenses. Mobile defenses are randomly encountered. Airborne interceptors are modeled during the ingress portion. As the aircraft flies within range of unsaturated defenses the output of one-on-one models is consulted and a random number is drawn to determine if the aircraft is killed.

The modeling of each defense includes a statistically derived table of terrain masking around defenses. This table gives mask angle as a function of the bearing of the aircraft from the defense. The modeling of the defenses includes the response time and potency of the defense as a function of the aircraft profile vector relative to the location of the defense.

Summarizing the Results of the Monte Carlo Runs

The interactions of the aircraft and the defenses are modeled in extreme detail. Although the potency of Soviet defenses in a future war is necessarily subjective, the models provide specific profiles against specific threats in given locations. The second-by-second potency of the defense in each case is the output of other models and uses data that has been furnished by AF Intelligence and approved by AF operators.

Since attacks on the same target with different munitions may use the same ingress and egress profiles, the attrition data from a series of Monte Carlo runs are stored in a segmented data bank. Given the configuration of a particular attack (target, munition, weather, and aircraft type) a retrieval program searches the data bank generated by numerous runs of the attack model and computes the resultant attrition rate for the particular attack.

ATTRITION—SUMMARY

Some believe that the AF NCAA process is biased toward expensive munitions.

A bias in the relative attrition rates for first day/first wave attacks with different munitions could cause a bias in the NCAA process. I could find nothing in the AD/ENYS attrition models and the way they are used (exclusive of the input data) that would result in a significant bias.

An important, and subjective, input to this process that could cause differential biasing between munitions is the weapon employment profile. In other words, if an IIR Maverick will generally require a longer, or higher, straight and level flight path after pull up than the profile that is modeled, that discrepancy would introduce a bias that would understate attrition for this munition and would bias the requirement in favor of IIR Mavericks.

The weapon employment profiles are primarily based on data supplied by the Tactical Fighter Weapons Center at Nellis AFB. They are reviewed by the Munitions Working Group. That doesn't mean that they are perfect, but the information is solicited from the best informed sources and is reviewed by a concerned group that includes many pilots.

Examining and evaluating the employment profiles submitted to AD/ENYS and their supporting arguments was deemed not worthwhile. Such an examination would be extremely time-consuming. Moreover, the important questions about these profiles are

not apt to be answered with someone's data base. The final opinions about the most likely weapons employment profile—by the people with the assigned responsibility—are apt to be qualitative and subjective.

Another input to the process is the nature of the expected defenses. Again, the defenses modeled are based on information supplied by AF Intelligence and are approved by AF operators.

Neither of these inputs appears to be intentionally biased. In both cases AD/ENYS has consulted with the AF offices having responsibility and had the inputs and the outputs approved by the Munitions Working Group.

With these possible exceptions, nothing I have learned about the NCAA process, and the expected attrition rates used in this process, would result in a substantial bias toward a preference for expensive weapons.

However, understating the aircraft and crew replacement cost by using aircraft flyaway costs, as though the aircraft could be purchased, stored, and rolled out in theater as needed, causes a bias away from the safer (and generally more expensive) munitions. Aircraft must be flown, maintained, and have a trained flight crew to be of value in war.

Further, as mentioned elsewhere, ignoring the OVLS may cause an even more substantial bias in favor of cheap and inefficient weapons in the current NCAA computations.

VII. MUNITIONS REQUIREMENTS CALCULATIONS VS. MUNITIONS ACQUISITION

The NCAA contains the executive summary of the Air Force Conventional Munitions Acquisition Plan (MAP), which is designed to serve as a planning input for the POM and guide the procurement of munitions in the absence of complete funding for the NCAA requirement. (The NCAA requirement, first published for the 1985–1989 POM, has never been completely funded.)

The MAP contains an ordered Munitions Priority List, which gives three top priority weapons lists, one for procurement, one for full scale development, and one for technology—that is, for further R&D.

Other than a statement of the summary of the MAP there is little formal connection between the NCAA and munitions acquisition process. The WRM panel controls munitions acquisition. At the time of writing Col. Clough, the Deputy Director of XOXFC, is the Chief of the WRM Panel. The methodology and the results in the NCAA are apparently used as guidelines in the acquisition process.

XOXFC staff indicated there is a chicken and egg problem with respect to new weapons in the NCAA. The NCAA does not include a weapon until a decision has been reached to fund procurement of the weapon. The implication is that there is not a requirement, hence not a need to procure, until a decision to procure has been made. Although this approach has a curious logic, it keeps XOXFC from having to wrestle with the problem of when to start funding the acquisition of a weapon that has been in development.

The NCAA models could have a unique niche in formulating a weapons R&D program. The models provide a means of identifying the need and potential market for hypothetical munitions defined only by their parameters—Pk, cost, and a notion of the weapon delivery profile that would allow estimates of aircraft attrition. Several runs of the NCAA models could provide an estimate of the desired buy as a function of cost.

VIII. SUMMARY

THE MALDISTRIBUTION PROBLEM

The Air Force maldistribution problem may be unlike that of the other services. First, the Air Force will fight from a fairly small number of fixed locations. Further, because not all weapons are used on all aircraft, even fewer bases use a given weapon. The bulk of the munitions are stored at depots, not at the air bases where they will be needed.

The central storage of munitions creates an acknowledged transportation problem at the onset of, and throughout, a NATO war. As mentioned in Sec. II, if a wing of F-16s was dedicated to air-to-surface, carrying Mk 82s and flying a 3.0 sortie rate, they would deliver about 1300 Mk 82s a day. This would require almost 20 truckloads of munitions a day from the depot to the F-16 base. Thus, there is a substantial storage and transportation problem, but the solution is not to buy more weapons. The problem could be alleviated somewhat by buying more efficient munitions. NCAA models ignore these distribution problems.

ADHERING TO THE DEFENSE GUIDANCE

In general the DG is closely followed. An important exception is the declaration [4, p. 52] that the services will compute a mix of current and new munitions that will "maximize early combat power and sustain combat objectives." If the OVLS is ignored in the munitions requirements calculation there will be a shortage of efficient munitions. This will have the effect of reducing early combat power, or reducing sustainability, or both.

Estimating the OVLS requires prorating the value of an aircraft throughout, and beyond, an envisioned conflict. After this is done it is fairly simple to include the OVLS in the selection of the preferred weapon in the SELECTOR model. This would bring the NCAA closer to the guidance in the DG and, by providing more efficient munitions, would increase the effectiveness of the aircraft.

TREATING UNCERTAINTY

Statistical uncertainty about the ability of the required munitions to kill the target set is handled well in the TO calculation. Although it gets no explicit treatment in the additive calculation it may be implicitly handled there by using conservative estimates of the needed parameters. If deemed important, the additive calculation could include explicit consideration of statistical uncertainty. (Suggestions for this are contained above in the section on the additive calculation.)

With the exception of using a distribution for weather, explicit consideration of uncertainty is avoided in the LOE calculation, where there is no previous formal or explicit determination of the total target value to be killed. (There is also little or no formal consensus on the value of killing any given target.) The intent of the model is to allocate least cost to kill munitions to the fixed and constrained number of aircraft sorties in a manner that maximizes the target value killed.

There are many different ways that statistical uncertainty could be included in this calculation, but in my judgment they would add little or nothing to the plausibility of the results of a model operating within this framework.

ATTRITION RATES

The attrition rates used in the NCAA are based on an extremely detailed and complex set of models run by AF/AD/ENYS. These models use the best information available on Soviet defenses and weapon employment tactics to model the expected attrition on the first wave of attacks on the first day of the war. These first day/first wave rates are attenuated by multipliers (which are not munition or aircraft dependent) to keep attrition in line with the WMP attrition rates. Despite concerns to the contrary, in my opinion the first day/first wave was modeled objectively and, considering the nature of the problem and the necessary data, accurately.

IGNORING THE OVLS

The biggest problem with the LOE calculation is not the "soft" nature of its objectives (as opposed to the precise or "hard" objective of the TO calculation) it is its focus on least cost to kill munitions, without regard for the substantial Opportunity Value of Lost Sorties incurred when cheap but inefficient weapons are used. The existing focus may limit the Air Force's ability to kill targets in the crucial early days of a war, and

certainly affects the number of efficient munitions left after the initial days. In doing so it diminishes the military worth of aircraft that are purchased, maintained, and based in theater, at substantial cost, in order to have a quick strike capability in the early days of a war.

If estimated values of the OVLS for different aircraft types were available they could easily be incorporated in the SELECTOR model. With these changes the model would then provide a preferred and more germane criterion. Running the sequence of NCAA models with this different criterion and suitably escalated values for targets killed early in the war would provide a direct comparison of the results of using the least cost to kill munitions (as currently defined) and of using a munition that is preferred for both its cost and its efficiency.

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